FRICTION PROPERTIES OF REED STALKS

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Abstract. One of the most important phenomena accompanying numerous processes biomass materials undergo is friction. The identification of the friction processes for plant materials is necessary for the correct design of many technological processes during which they are transported, chopped, or stored. Most research on friction uses the simple Coulomb model. To determine the coefficient of friction, an adjustable tilt plate is used, on which the material under study is placed. The coefficient of static friction was taken as the tangent of the angle of the inclined plate at which the material begins to slide. Friction can be determined by moving biomass against horizontal surfaces of different materials. Common materials for friction pairs with biomass were steel plates, wood, glass and rubber. Common reed (Phragmites australis) is a grass which has spread nearly all over the globe. Considering that the reed stalk is a natural tube, it can be used to make cocktail straws. However, there is a much wider range of uses, such as toy components, room decors etc. Such applications require that the reed stem is not flattened after cutting. Likewise, the end of the stem must be free of sharp edges and smooth. In previous studies, non-destructive cutting of reeds using abrasive discs was evaluated. In order to create a device for non-destructive cutting of reeds, it is necessary to know the coefficient of friction of the reed stalk. This paper analyses friction parameters of reed stalks of different diameters. As a result of the research, the values of friction coefficients for reed against various plastics, metals and rubber were obtained. The coefficient of friction of reeds against hard materials (both metals and plastics) ranges from 0.12 to 0.37. A significant difference depending on the diameter of the reed is not observed. The highest values of the coefficient of friction are between reeds and rubber, from 0.81 (transverse direction) to 1.02 (longitudinal direction).

Keywords: common reed, friction properties, friction coefficient, non-destructive cutting.

Introduction

Common reed is a highly competitive invasive plant capable of rapid growth and spread, often threatening the biodiversity of natural and rewetted wetlands [1]. Common reed is mainly used for raw material extraction or energy generation, usually through direct combustion [2; 3]. However, reeds have many other uses, they can be used as decorative elements in everyday interiors, they can be used for carpets, wall coverings, cocktail straws, Christmas decorations and kids' toys [4]. In further studies of non-destructive cutting of reeds for material selection of the grab mechanism, the coefficients of friction between the reeds and various materials were determined both in the transverse and longitudinal directions.

There are different types of friction: the static friction is the frictional force acting between two surfaces which are attempting to move, but are not moving, while the kinetic friction is the frictional force acting between two surfaces which are in motion against each other. Friction coefficients clearly affect the grip results [5]. However, no comprehensive study of friction coefficients between reeds and different materials has been conducted at present.

The measurement of the static coefficient of friction using the variable incidence tribometer method is defined in the standard ASTM D1894-08 [6], ASTM D4917-97 [7], ASTM D4521-96 [8], ISO 12957-2 [9], TAPPI T815 [10], ASTM F1679-04e1 [11], ASTM D4918-97 [12].

(a) (b)

Fig. 1. **Method of inclined plane for the measurement of the static coefficient of friction (a); Method for the measurement of the kinetic coefficient of friction (b) [13]**

The tangent of this angle in Fig. 1 is the static coefficient of friction. The measurement of the static coefficient of friction simply consists of increasing of the angle of the inclined plane until the moment when the slipping of sled on the inclined plane is initiated [14].

The static friction arises when the object is stationary relative to the surface. Once the applied force exceeds this value, the object starts to move, and the static friction ceases to exist. The kinetic friction arises when the object moves relative to the surface after the applied force overcomes the static friction [13].

Materials and methods

In order to determine the coefficient of friction for reeds with different materials, a device for determining the coefficient of friction was developed at the Institute of Mechanics.

The purpose of this study was to determine the material that has the highest coefficient of friction with the reeds to ensure a sufficiently high adhesion force with the jaws of the clamping mechanism. In order not to damage the structure of the reed, it should be grasped with a force in the range of 28.9-56.14 N [15].

Friction is the resistance that one body creates to the motion of another body as it slides over the first. The friction force F_f (Fig. 2) is tangent to the surfaces of contact of common reeds and other material and always opposes the motion.

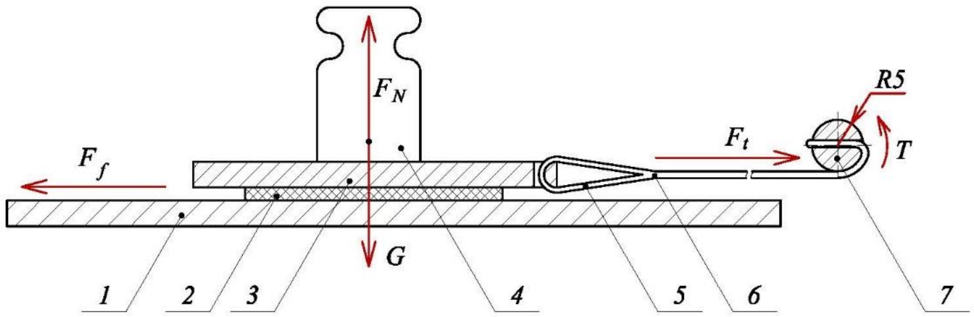

Fig. 2. **Experimental equipment for determining the coefficient of friction:** 1 – test material; 2 – common reed; 3 – base plate to which the reeds are glued; 4 – weight; 5 – Kevlar leash; 6 – rolling swivel; 7 – roll

The friction coefficient was investigated by moving reeds flattened and glued to a plate against horizontal surfaces of different materials. The surfaces were aluminum, bronze, rubber, latex, ferrous metal, plastic, tin, galvanized tin, anodized aluminum, ertalon, stainless steel, technical aluminum, polished tin, ABS (acrylonitrile butadiene styrene) and cellulose triacetate. The square area between the surface and on the base plate glued reeds is 55×55 mm. The coefficient of friction for reeds with different materials was determined both in the transverse direction and also in the longitudinal direction, Fig. 3.

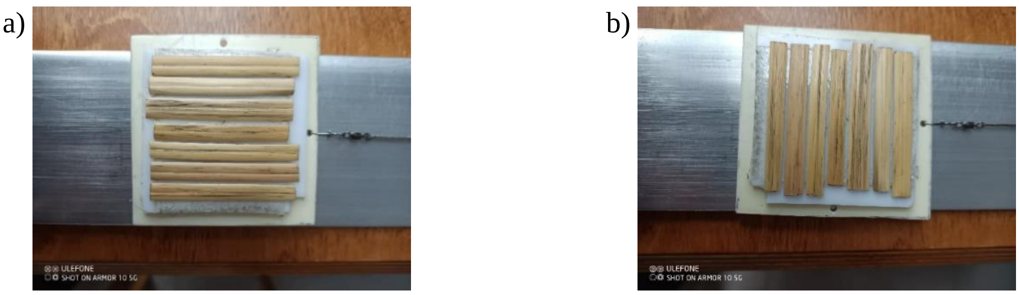

Fig. 3. **Position of reeds in longitudinal (a) and transverse (b) direction**

The base plate was loaded with a force of 20 N. The horizontal speed was controlled using a frequency converter and motor reduction gear, it was 10 min^{-1}. The diameters of the reeds used in the experiments were 5, 7 and 10 mm. For each reed sample of the specific diameter (5, 7 and 10 mm) with each material in the longitudinal and transverse directions, the experiment was carried out 11 times.

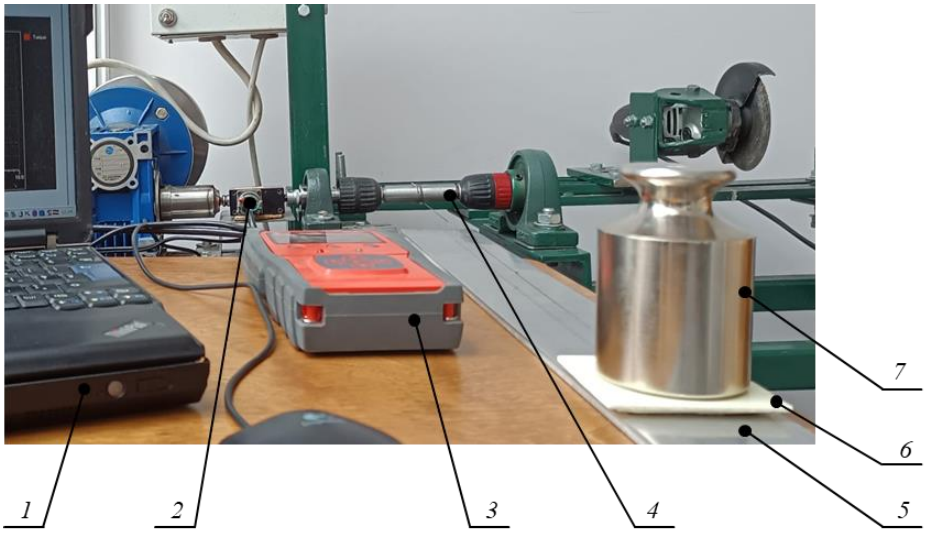

Fig.4. **Experimental equipment:** 1 – computer; 2 – torque transmitter; 3 – measuring equipment MOUNTZ; 4 – roll, 5 – test material; 6 – plate with specimens of reeds affixed; 7 – weight

The calculation for the kinetic friction coefficient μ_k is done according to equation (1)

$$\mu_k = \frac{F_f}{F_N} = \frac{T}{rG}, \tag{1}$$

where μ_k – kinetic friction coefficient;
F_f – friction force,N;
F_N – normal force,N;
T – torque,Nm;
G – weight,N;
r – radius,m.

The traction force F_t (Fig. 2) is measured using the MOUNTZ torque gauge Torque mate PTT. The meter is equipped with a software that provides signal filtering and obtained calibration data registration in the computer (Fig. 4). The torque gauge provides an accuracy ± 0.5% of full scale. To measure the torque a smart sensor RTSX50i-A was used with a measuring range of 565 cNm. Non-linearity of the sensor is ± 0.2%. Interchangeability error does not exceed ± 0.3%. Gauge bridge resistance is 350 Ω.

Fig. 5 shows result of the measurements, the change in the torque over a certain period of time was obtained. Data were tabulated and entered into Excel.

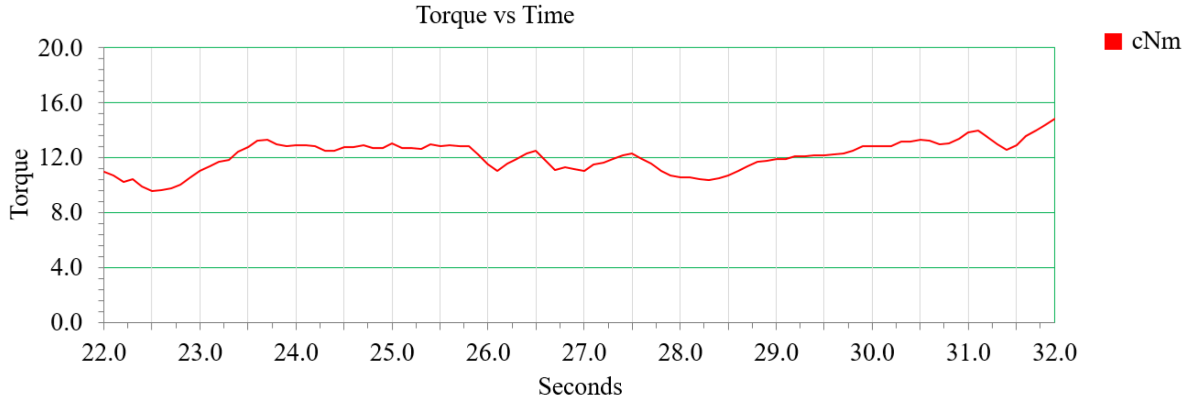

Fig. 5. **Graph of the torque change obtained in the experiment**

During the experiment, changes in the torque were observed (Fig. 5) caused by the variable internal friction between the gears and the joints of the experimental equipment. To eliminate errors due to internal friction in the mechanism, series of idle measurements were made and the idle torque was calculated. In the calculations, the idling torque was subtracted from the experimental result.

Results and discussion

In previous studies, it was found that it is necessary to cut reed without flattening it. An appropriate method and device was developed to ensure such cutting. The reed is fixed in a special gripping mechanism that prevents the stem from moving during the cutting process [15].

The results of the experiments were processed using Excel data analysis tools and the average values of the friction coefficients were obtained. The results of the experiments are summarized in Table 1.

Table 1

Average common reed friction coefficient with various materials

Direction	**Longitudinal**			**Transverse**		
Material \ **Diameter, mm**	**5**	**7**	**10**	**5**	**7**	**10**
Rubber	0.98	1.07	1.00	0.74	0.85	0.84
Bronze	0.28	0.33	0.31	0.35	0.37	0.31
Latex	0.28	0.30	0.27	0.30	0.35	0.29
Technical aluminum	0.22	0.27	0.26	0.24	0.28	0.26
Plastic	0.21	0.25	0.20	0.24	0.27	0.19
Stainless steel	0.18	0.22	0.21	0.22	0.25	0.22
Ferrous metal	0.17	0.20	0.21	0.21	0.19	0.22
Tin	0.18	0.19	0.18	0.22	0.20	0.23
Galvanized tin	0.18	0.19	0.16	0.22	0.23	0.19
Cellulose triacetate	0.18	0.18	0.20	0.19	0.18	0.20
Polished tin	0.22	0.16	0.13	0.21	0.20	0.16
Aluminum	0.18	0.12	0.13	0.21	0.16	0.17
ABS	0.20	0.13	0.16	0.18	0.17	0.15
Anodized aluminum	0.12	0.13	0.13	0.20	0.16	0.13
Ertalon 6PLA	0.16	0.10	0.11	0.16	0.18	0.12

It can be seen from Table 1 that the coefficient of friction of reeds against hard materials (both metals and plastics) ranges from 0.12 to 0.37. A significant difference depending on the diameter of the reed is not observed (Table 1). The biggest difference between the coefficient of friction in the transverse and longitudinal direction was found for rubber (Table 1). This can be explained by the fact that the surface of reed is slightly grooved in the longitudinal direction. The rubber is soft and the grooved surface digs into the material, creating increased friction for transverse movement.

Analysis of variance (ANOVA) was used to analyze differences between the materials and direction. The results of the statistical analysis of the data are summarized in Table 2.

Table 2

Analysis of variance (ANOVA)

Source of variation	***SS***	***df***	***MS***	$F_{fact.}$	***P-value***	$F_{crit.}$
Between materials	1.009497	14	0.072107	**40.31284**	7.35E-09	**2.483726**
Between directions	0.000485	1	0.000485	**0.271191**	0.610672	**4.60011**
Total	1.035024	29	-	-	-	-

After performing the analysis, it can be concluded that $F_{fact.} = 40.31284 > F_{crit.} = 2.483726$, then with a probability of 95% the null hypothesis can be rejected and the alternative hypothesis that the friction coefficient depends on the material can be accepted. After performing the second analysis, it can be concluded that $F_{fact.} = 0.271191 < F_{crit.} = 4.60011$, then with a probability of 95% the null hypothesis can be accepted that the friction coefficient does not depend on the direction (for hard materials, excluding rubber).

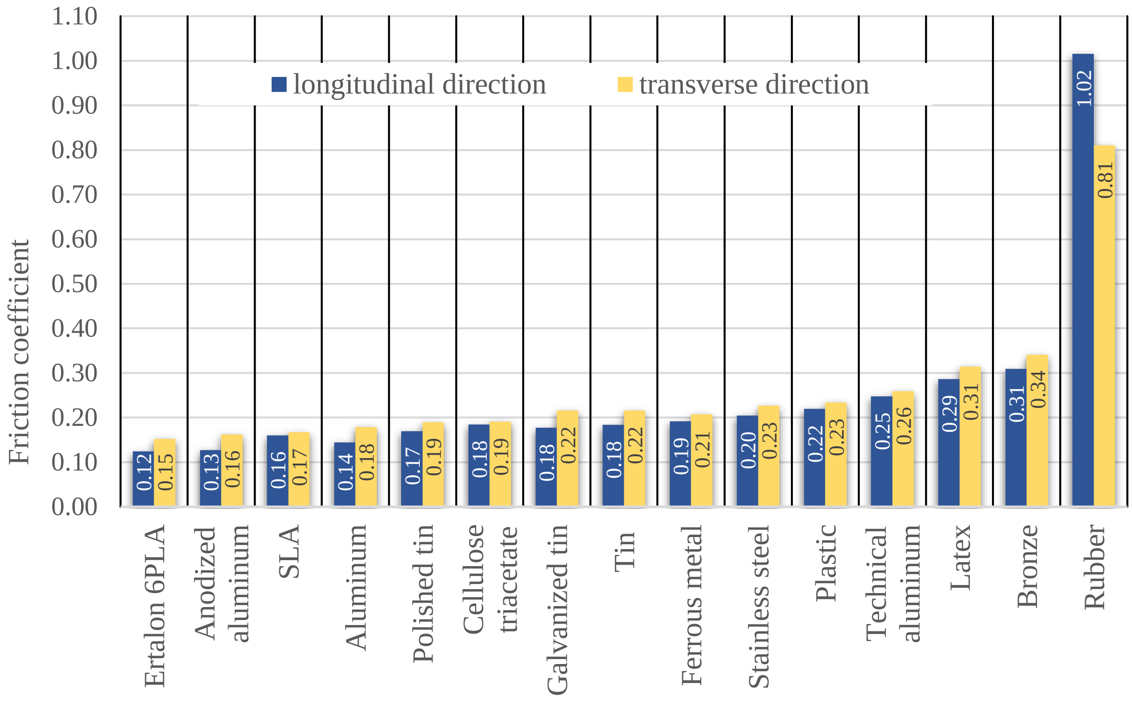

Fig. 6. **Friction coefficient between reed and various materials**

The average values of the coefficient of friction for different materials are summarized in Fig. 6. The highest values of the coefficient of friction are between reed and rubber, from 0.81 (transverse) to 1.02 (longitudinal). In the previous studies of chopped straw, reed and energy crop friction determined dynamic coefficient of friction depending upon the surface material varies from 0.15 (steel) to 0.6 (rubber) [16].

Analysis of variance (ANOVA) was used to analyze the differences between the coefficient of friction in the longitudinal and transverse directions between reeds and rubber. After performing the analysis, it can be concluded that $F_{fact.} = 5.803042 > F_{crit.} = 4.351244$, then with a probability of 95% the null hypothesis can be rejected and the alternative hypothesis that the friction coefficient of rubber depends on the direction can be accepted.

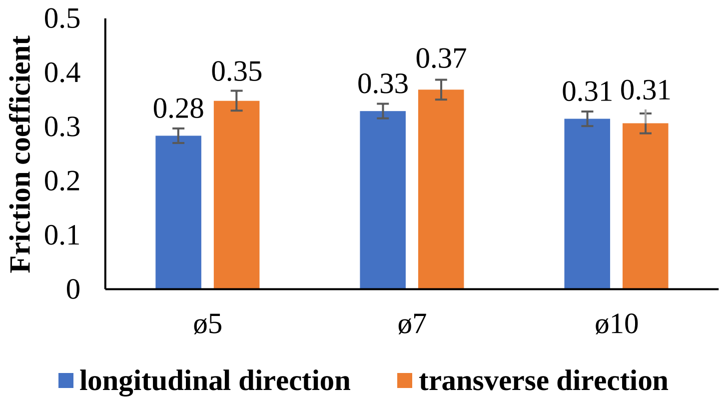

Fig. 7. **Friction coefficient between reed and bronze**

From this point of view, the rubber coating on the gripper jaws will provide the least amount of clamping force to secure the reed in the cutter. However, it should be noted that rubber is a soft material and can wear out quickly over time.

The highest coefficient of friction for hard materials was found for reed against bronze (Fig. 7). In addition, it is larger in the transverse direction than in the longitudinal direction. This is essential for ensuring high-quality operation of the gripper.

Conclusions

1. The coefficient of friction of reeds against hard materials (both metals and plastics) ranges from 0.12 to 0.37. A significant difference depending on the diameter of the reed is not observed.
2. The highest values of the coefficient of friction are between reeds and rubber, from 0.81 (transverse direction) to 1.02 (longitudinal direction).
3. After performing the analysis of variance, it can be concluded that $F_{fact.} = 0.271191 < F_{crit.} = 4.60011$, then with a probability of 95% the null hypothesis can be accepted that the friction coefficient does not depend on the direction (for hard materials, excluding rubber).
4. After performing the analysis of variance, it can be concluded that with a probability of 95% the hypothesis that the friction coefficient of rubber depends on the direction can be accepted.
5. The highest coefficient of friction for hard materials was found for reeds against bronze, on average 0.33. In the transverse direction, it is slightly larger than in the longitudinal direction, this is essential for ensuring the high-quality operation of the gripper.

Author contributions

Conceptualization and methodology, A.K.; validation, O.V.; formal analysis, A.K and O.V.; investigation and data curation, O.V.; writing – original draft preparation, O.V.; writing – review and editing, A.K. and O.V. All authors have read and agreed to the published version of the manuscript.

References

[1] Czubaszek R., Wysocka – Czubaszek A., Wichtmann W., Zajac G., Banaszuk P. Common Reed and Maize Silage Co-Digestion as a Pathway towards Sustainable Biogas Production. Energies, MDPI, vol. 16(2) 2023, pp. 1-25.
[2] Köbbing, J.F., Thevs, N., Zerbe, S. The Utilisation of Reed (Phragmites australis). Mires Peat 2013(13), pp. 1-14.,
[3] Gómez-Sánchez, M.D., Sánchez, R., Espinosa, E., Rosal, A., Rodríguez, A. Production of Cellulosic Pulp from Reed (Phragmites Australis) to Produce Paper and Paperboard. Bioprocess Engineering, vol. 1(3) 2017, pp 65-68.
[4] Nulle I., Kakitis A., Vronskis O., Smits M. Cutting the common reed stalk while maintaining its cross-sectional shape. Proceedings of International conference “Engineering for rural development”, May 20-22, 2020, Jelgava, Latvia, pp. 357-361.
[5] Dorn M., Habrova K., Koubek R., Serrano E. Determination of coefficients of friction for laminated veneer lumber on steel under high pressure loads. Friction, vol. 9(2)2021, pp. 367-379.
[6] ASTM D1894-08 standard “Test Method for Static and Kinetic Coeffcients of Friction of Plastic Film and Sheeting”.
[7] ASTM D4917-97(2007) standard “Test Method for Cofficient of Static and Kinetic Friction of Uncoated Writing and Printing Paper by Use of the Horizontal Plane Method”.
[8] ASTM D4521-96 standard “Test Method for Cofficient of Static Friction of Corrugated and Solid Fiberboard”.
[9] ISO 12957-2:2005 standard “Geosynthetics – Determination of Friction Characteristics – Part 2: Inclined Plane Test”.
[10] TAPPI T815 standard “Coeffcient of Static Friction of Packaging and Packaging Materials”.
[11] ASTM F1679-04e1. standard “Test Method for Using a Variable Incidence Tribometer”.
[12] ASTM D4918-97 standard “Standard Test Method for Coe_cient of Static Friction of Uncoated Writing and Printing Paper by Use of the Inclined Plane Method”.
[13] Friction. [online] [20.03.2023] Available at: https://www.sciencefacts.net/friction.html
[14] Kelemenova T., Dovica M., Bozek P., etc. Specific Problems in Measurement of Coeficient of Friction Using Variable Incidence Tribometer. Symmetry in Mechanical Engineering II. 2020, [online] [20.03.2023] Available at: https://www.mdpi.com/2073-8994/12/8/1235
[15] Vronskis O., Kakitis A., Nulle I., Šmits M. Evaluation of the transverse strength of reed stalks. Proceedings of International conference “Engineering for rural development”, May 25-27, 2022, Jelgava, Latvia, pp. 612-617.
[16] Kakitis A., Nulle I. Friction of chopped straw. Proceedings of International Scientific Conference. “Agriculture engineering problems”, June 2-3, 2005, Jelgava, Latvia, pp. 143-148.